Solid-State Ultraviolet Irradiation for Continuous Disinfection of Occupied Spaces

Kevin Benner

GE Current, a Daintree company

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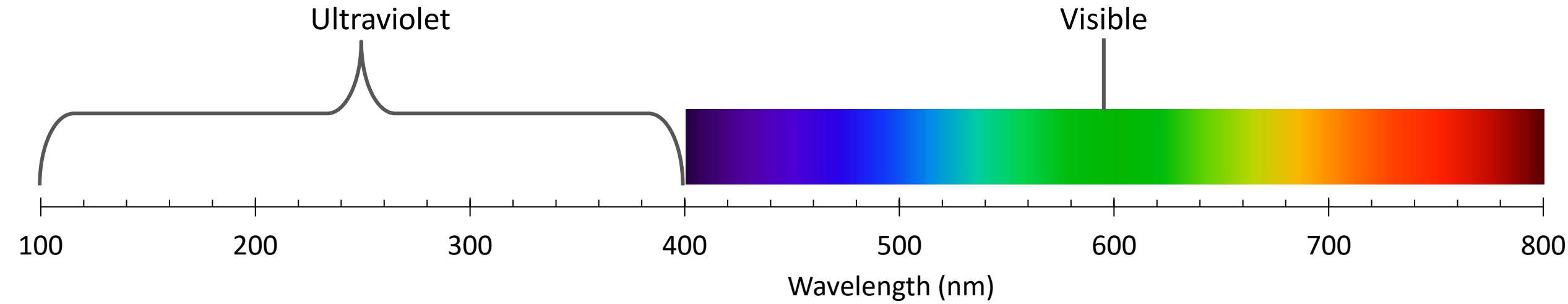
Make an Informed Decision:

365DisInFx™ technology

- UV radiation can pose a risk of personal injury. Overexposure can result in damage to eyes and bare skin. To reduce risk of overexposure, equipment must be installed in accordance with manufacturer's site planning and application recommendations, including minimum ceiling height restrictions.
- UV solutions are intended for common high traffic spaces and not recommended for dwellings or home use.
- Installation of the devices should be performed by qualified professionals as detailed in Current's installation guide.
- To allow for occupancy during use, Current products comply with IEC 62471 – Photobiological Safety of Lamps and Lamp Systems standards and American Conference of Governmental Industrial Hygienists (ACGIH®) TLVs® guidelines when installed as directed.
- Current's UV products are meant to be used in conjunction with other protective measures like manual cleaning and the use of proper PPE. They are not a substitute for other measures.
- Current products are not intended for use as a medical device.
- If combining two or more UV solutions, whether from GE Current, a Daintree company and/or other manufacturers, please consult a trained product application representative to ensure the total irradiance (UV dose) does not exceed recommended human exposure limits. To the extent UV solutions are combined, it may impact inactivation rates.

Germicidal irradiation for occupied spaces: wavelength selection



Increasing germicidal efficacy

Decreasing photobiological risk*

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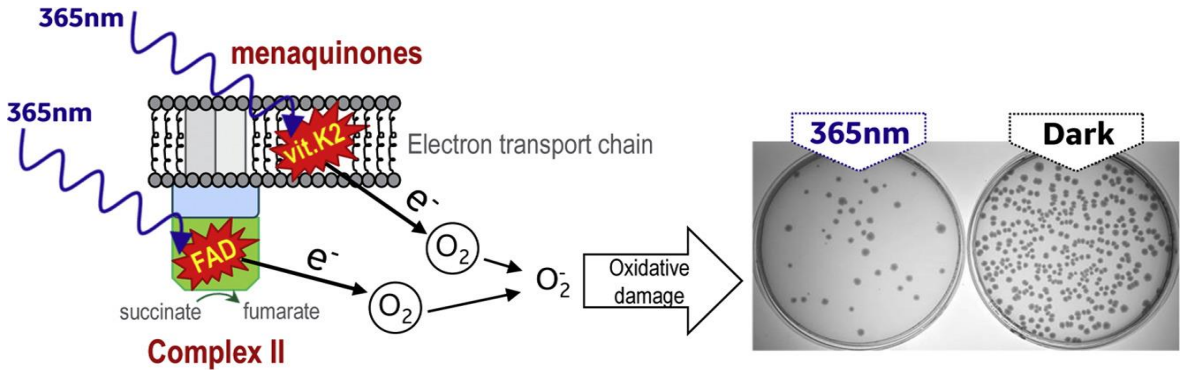
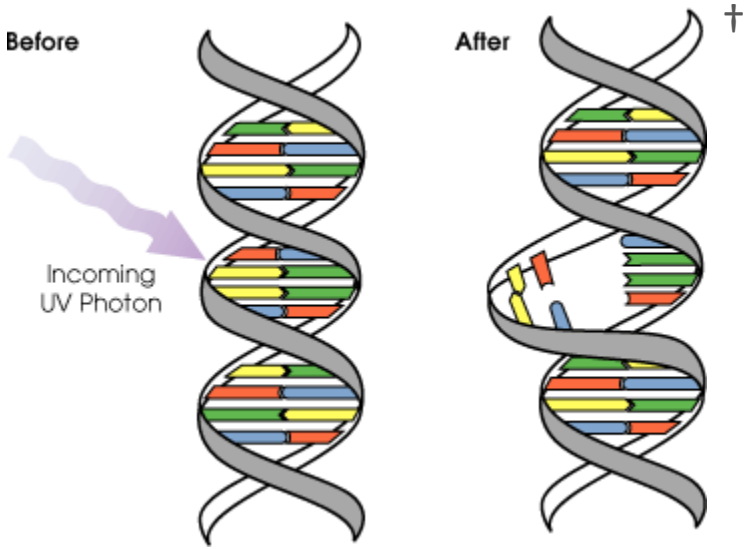
*Based on spectral weighting function for assessing ultraviolet hazards for skin and eye as defined in IEC 62471.
CEI/IEC. 62471:2006 Photobiological safety of lamps and lamp systems. 2006:1-90

Mechanism of inactivation (365nm)



Excitation of endogenous chromophores in the electron transport chain leads to the formation of superoxide radicals causing loss of respiration and oxidative damage leading to cell death (study in *E. coli*).*

Mechanism of inactivation (254nm)



UVC can inactivate microorganisms by causing the formation of molecular lesions such as pyrimidine dimers when the UVC photons are absorbed by nucleic acids (RNA or DNA) in a microorganism.‡

*Kvam E, Benner K. Mechanistic insights into UV-A mediated bacterial disinfection via endogenous photosensitizers. *Journal of Photochemistry and Photobiology B: Biology*. 2020;209:111899. doi:10.1016/j.jphotobiol.2020.111899.

†Image credit: NASA/David Herring

‡ Chun-Chieh T, Chih-Shan L. Inactivation of Viruses on Surfaces by Ultraviolet Germicidal Irradiation, *Journal of Occupational and Environmental Hygiene*. 2007; 4:6, 400-405, doi:10.1080/15459620701329012

UVC germicidal irradiation for occupied spaces

- Direct inactivation mechanism of UVC is needed to inactivate most viruses, compared to indirect mechanism of UVA for bacteria and fungi
- Can UVC be useful for reduction of pathogens, particularly viruses, at doses below the IEC 62471 exposure limit?

UVC germicidal irradiation for occupied spaces

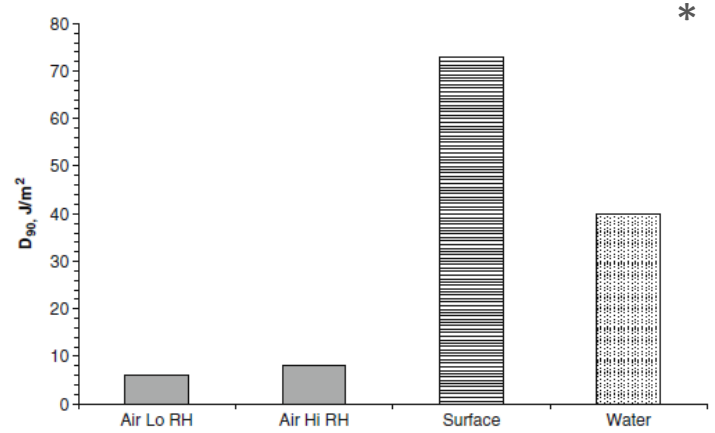


Fig. 4.3 Comparison of overall averages for virus D_{90} values in various media

*

	Air	Surface	Water
Wavelength (nm)	254	254	254
Approximate average virus D90 (J/m²)*	7	70	40
ACGIH TLVs®† or IEC 62471 EL‡ (J/m²)	60	60	60
EL/D90	8.6	0.9	1.5

$\log_{10}$-reduction of pathogen at IEC 62471 exposure limit

- At 254nm, several-$\log_{10}$ inactivation is possible for viruses in air at exposures below ACGIH TLVs® and IEC 62471 exposure limit
- Virus inactivation on surfaces is much less than in air at the same doses

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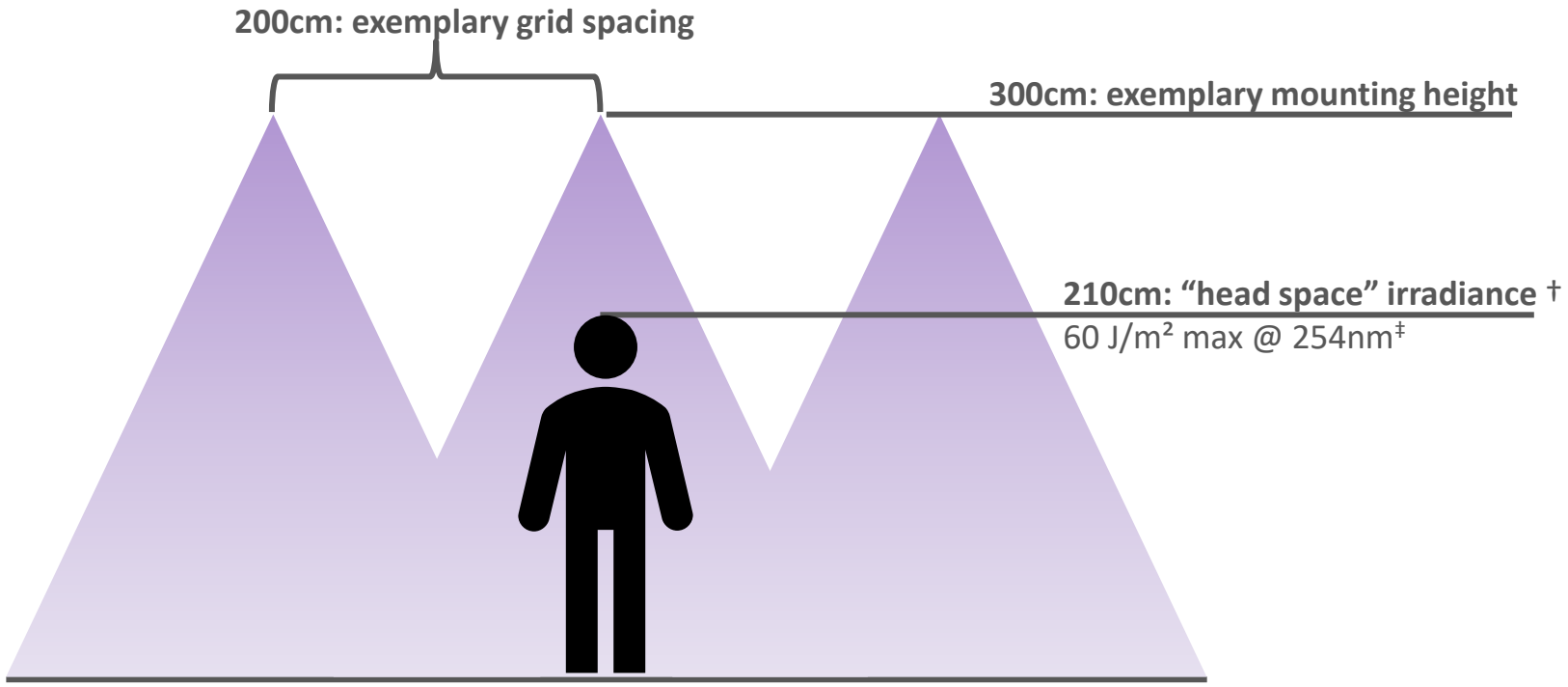
*Kowalski W. Ultraviolet Germicidal Irradiation Handbook. 2009:82.
†ACGIH. 2020 TLVs and BEIs. 2020:155-160
‡CEI/IEC. 62471:2006 Photobiological safety of lamps and lamp systems. 2006:1-90

Application and geometry for UVC whole room irradiation below IEC 62471 exposure limit

- Max dose at 2.1m (80° cone) determines exposure limit compliance
- Average dose (average for whole room) determines effectiveness



- 0.9 AVG:MAX ratio is achievable
- ~54 J/m² = ~8-$\log_{10}$ inactivation of aerosolized viruses without exceeding EL in occupied space
- ~1-$\log_{10}$ inactivation of "average virus*" in 1 hour if dose is applied over 8 hours

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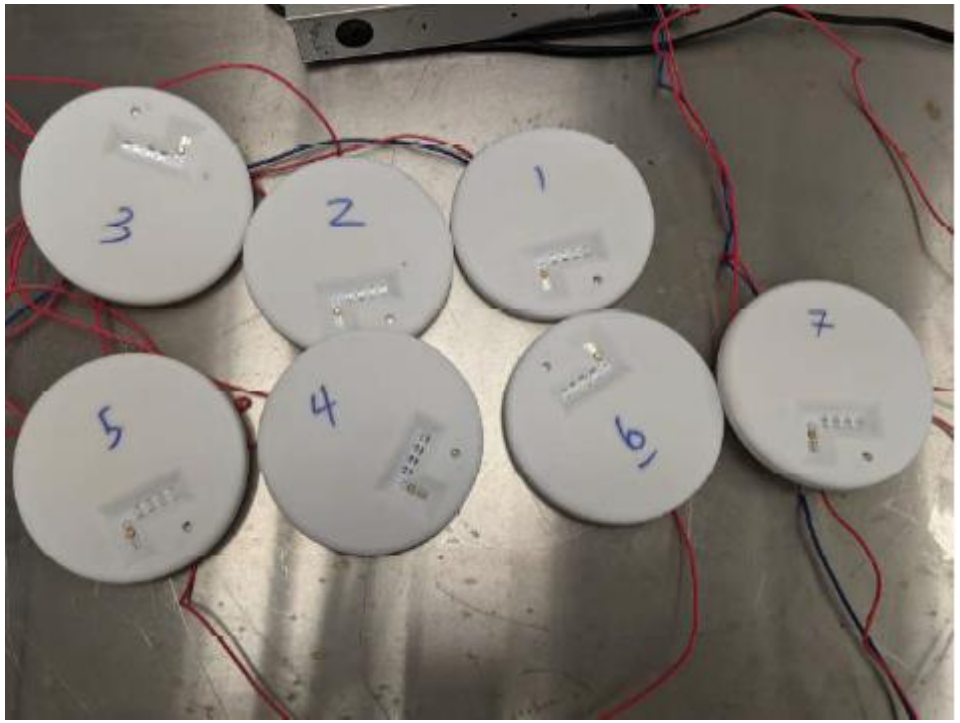
*Virus with D90 of 7 J/m² in air, per Figure 4.3 of Kowalksi 2009
Kowalski W. Ultraviolet Germicidal Irradiation Handbook. 2009:82.
†Standard for Luminaires, UL1598
‡ CEI/IEC. 62471:2006 Photobiological safety of lamps and lamp systems. 2006:1-90

Prototype device and surrogate test

- UVC LED whole-room irradiation devices with peak wavelength 258nm
- Room-scale BSL1 test chamber
  (10ft W x 10ft D X 8ft H)
- Aerosolized surrogate virus (bacteriophage MS2*)



Prototype devices
(Single UVC LED with Wp ~258nm)
~1.7mW radiated per device (enabled by LED)

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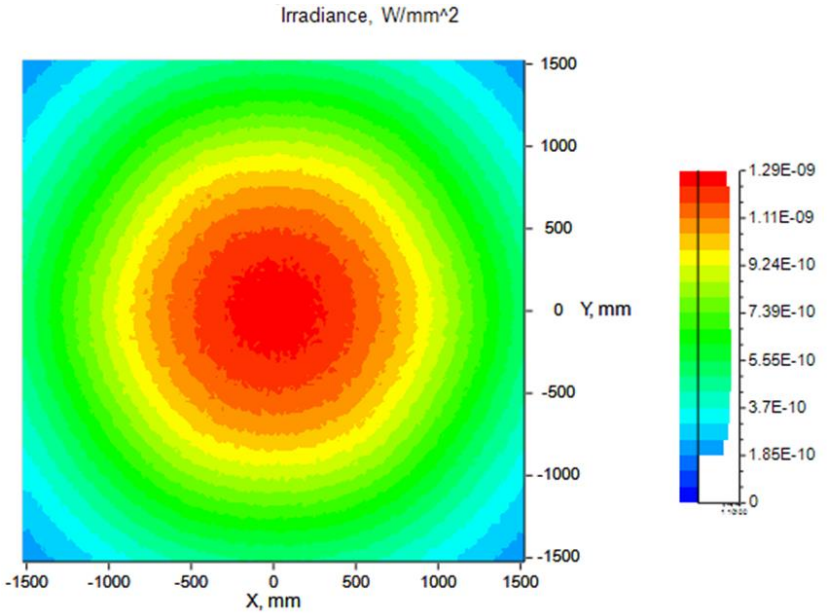
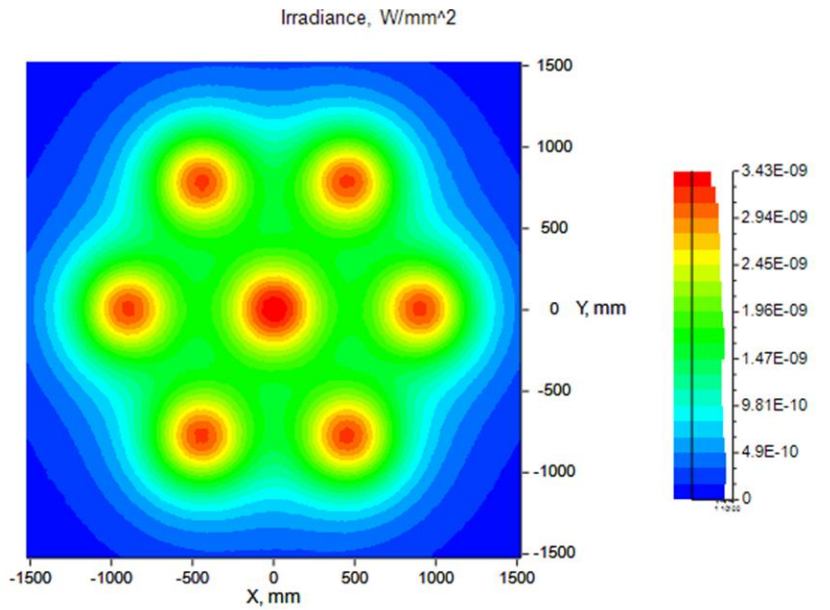
**Escherichia coli bacteriophage MS2* (ATCC® 15597-B1™)*

Room-scale chamber and test*



Average room dose: ~10J/m²



Max headspace dose: ~46J/m²

Prototype devices mounted in test chamber

- Low ceiling and small room = low AVG:MAX ratio (0.2 vs up to 0.9 in large room)
- 4-hour exposure

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*Custom aerosol study by Microchem Laboratory, Round Rock TX

Test results

- 9.9 J/m² at Wp=258nm, delivered over 4 hours
- 0.93-$\log_{10}$ (88%) reduction of aerosolized bacteriophage MS2 vs control tests without UVC (triplicate measurements)*

Bacteriophage MS2 as a surrogate pathogen

- Use of a BSL1 organism allows testing of devices in full- or close to full-scale conditions, unlike BSL2 (or BSL3) organisms which would need to be used in a biosafety cabinet, requiring small-scale test setups.
- Bacteriophage MS2 is generally more resistant to inactivation than enveloped viruses.†

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* Microchem Laboratory. Study Report: Evaluation of Bioaerosols and Antimicrobial Efficacy of GE Current's Test Device. 2020
† Microchem Laboratory. MS2 Bacteriophage - A Viral Screening Tool.
https://microchemlab.com/information/ms2-bacteriophage-viral-screening-tool

Application of findings to an exemplary room, with special consideration to coronaviruses

	Test results	Exemplary room (modeled)
Room size	10ft W x 10ft D x 8ft H	Arbitrary size x 10ft H
Max headspace dose (J/m²)	46	40
AVG:MAX ratio	0.2	0.8
Average room dose (J/m²)	9.9	32
log_{10} reduction of MS2	0.93	3.0
log_{10} reduction of coronavirus (estimated)		29.8

Coronaviruses are ~10X easier to inactivate with UVC than MS2*
Application to seasonal coronaviruses and SARS-CoV-2 is reasonable

~30-log_{10} reduction of aerosolized coronaviruses by whole room irradiation may be possible without exposing occupants to doses exceeding the IEC 62471 exposure limit

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*Walker C, Ko G. Effect of Ultraviolet Germicidal Irradiation on Viral Aerosols. *Environ. Sci. Technol*. 2007;41,5460-5465

Exposure duration for whole room irradiation below IEC 62471 exposure limit

Time to 1-$\log_{10}$ (90%) reduction

Equivalent air changes per hour

Exposure Duration (hours)	t_{90} (minutes)*	ACH_{eq}
24	48-135	1-3
12	24-68	2-6
8	16-45	3-9
4	8-23	6-17

$$ACH_{eq} = \frac{-\ln(0.1) \times 60}{t_{90}}$$

(equation adapted from CDC Guidelines for Environmental Infection Control in Health-Care Facilities, Appendix B)†

Whole room irradiation below exposure limits would be expected to provide virus inactivation comparable to mechanical air changes ranging from 1-17 ACH, depending on UVC exposure duration

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*Minimum t_{90} based on coronavirus D90 inferred from previously shown MS2 test, maximum t_{90} based on assumption of D90 of 3.0 J/m²

†Centers for Disease Control and Prevention. Guidelines for Environmental Infection Control in Health-Care Facilities (2003). https://www.cdc.gov/infectioncontrol/guidelines/environmental/index.html

Technology summary—whole room irradiation below IEC 62471 exposure limit

- UVA irradiation below the IEC 62471 exposure limit has been proven to provide reduction of certain common bacteria and fungi on surfaces.
- UVC irradiation below the IEC 62471 exposure limit has been shown to provide reduction of viruses* in air.
- UV LEDs enable the emission of UVC and UVA into practical embodiments.

*Tested on bacteriophage MS2, with calculated extensions of findings to other organisms

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